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HIGH RESOLUTION SPECTROSCOPY OF THE NA EXOSPHERE OF MERCURY WITH THE 3.5M TNG

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Several spectra of the exosphere of Mercury in the Na-D lines were taken with the high-resolution spectrograph (SARG) of the 3.5m Telescopio Nazionale Galileo (Roque de los Muchachos, Canaries) on the evenings of August 23, 24 and 26, 2002. All spectra were taken at a resolution of 115.000, with a slit length of 26" centred on the disk of Mercury. The apparent magnitude of the planet was +0.1, the apparent diameter 6".3, the phase 0.60. The spectra were taken at several position angles, and they all show the expected emission lines across the disk and outside it.
The paper will present a detailed analysis of the results.

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Abstract – *Several spectra of the exosphere of Mercury in the Na-D lines were secured with the high-resolution spectrograph (SARG) of the 3.5m Telescopio Nazionale Galileo (Roque de los Muchachos, Canaries) on the evenings of August 23, 24 and 26, 2002. All spectra were taken at a resolution R = 115.000, with a slit length of 26" centred on the disk of Mercury. The apparent magnitude of the planet was +0.1, the apparent diameter 6".3, the phase 0.60. The spectra were taken at several position angles, and they all show the expected emission lines across the disk. Outside the disk there has been no detection.*

The present paper presents a first analysis of the results.

Introduction

Mercury is surrounded by a very tenuous atmosphere, with a measured dayside density of about 10^5 atoms/cm^3 (P = 10^{-12} bar). Due to the very low density, the atmosphere is collision-less, i.e. the mean free path of the atoms is shorter than the value of the scale height of the atmosphere (cf. Chamberlain & Hunten 1987). Therefore, the whole atmosphere is comparable with an exosphere having the exobase coincident with the planet's surface.

The existence of the atmosphere around Mercury was discovered for the first time by the Mariner 10 spacecraft, which revealed spectroscopically three atomic elements: H, He and O (Broadfoot et al., 1976). Other three elements (Na, K, and Ca) were later discovered with ground-based observations (Potter & Morgan 1985, Potter & Morgan 1986, Bida et al. 2000).

The lifetime for the species in the exosphere is ruled by the interaction with the interplanetary medium; photoionization is the fastest loss mechanism: the ionized atoms are driven away from the planet by the solar wind, or aimed back to the surface along the lines of the Mercury's magnetic field. To maintain the exosphere, the lost atoms must be replaced by some source mechanisms. Processes of endogenic and exogenic origin are supposed to act in repopulating the exosphere; in the case of Na, the expected sources include photon and electron stimulated desorption, ion and chemical sputtering, vaporisation of regolith and of projectiles following micrometeoritic impacts (cf. Smyth & Marconi 1995, Killen & Morgan 1997), and thermal evaporation. Regarding the latter, McGrath et al. (1986) had already concluded that thermal desorption would dominate at T > 400 K, while at cooler locations sputtering either by ions or UV would prevail.

As gas-phase collisions are negligible, each separate Mercury's gaseous element forms an exosphere having different parameters (T, H, n_0) with respect to the other species. This means that it is possible to follow the evolution of a particular exospheric component without taking into account the others. Exospheric atoms are liberated from the surface with a supra-thermal energy (i.e. with $T_{gas} > T_{surf}$) which depends on the nature of their source mechanism. They can gravitationally escape from the planet (escape velocity = 4.3 km/s), or go into a ballistic orbit which will re-encounter the planet's surface. After a bounce, the atoms can stick to the surface, or rebounce into another ballistic orbit with a different energy, closer to the temperature of the surface, until they are photoionized or readsorbed by the surface (cf. Hunten, Morgan & Shemanski 1986; Smyth & Marconi 1995). The number and the path of the bounces is determined by the nature of the gas-surface interactions, by the lifetime of the neutral atom in the exosphere, and of course by the gravity and radiation pressure. As the atoms can perform several bounces, it is expected that a thermal component exists near the source supra-thermal component, like on the

Moon, but at Mercury the thermal component should be the dominant one, because of the higher temperature and greater gravity (see Hunten and Sprague, 1997). Indeed, a measurement of the temperature of the Na component via high-resolution spectroscopy was performed by Killen et al. 1999. They found the presence of two components, a supra-thermal one (1500 K) and another one (600 K) much closer to the surface's temperature.

As already said, the exospheric alkaline components (Na and K) were first detected by ground-based observations in mid '80s (Potter & Morgan 1985, Potter & Morgan 1986). In the following years, many results of great interest were obtained; three of the prominent ones are:

?? the detection of rapid time-variations in the intensity of the exosphere, not correlated with changes in solar activity (Potter et al. 1999),

?? the enhancements of sodium emission over known geological features on Mercury's surface (e.g. Caloris Basin), and over regions which show radar-bright spots, associated with regions of fresh excavation or with volcanic features (Sprague et al. 1998),

?? the discovery of a sodium comet-like tail streaming anti-sunward (Potter et al. 2002)

Different conclusions are obtained by the various authors in the determination of the source mechanisms (see **Fig. 1**). In 1997, Sprague et al. found a strong diurnal variation in the emission of Na and K, with a large enhancement in the morning. They conclude that a recycling mechanism is at work, such that some photoionised atoms are driven back to the surface along the lines of the magnetosphere, then neutralised and adsorbed to the surface in the night hemisphere, then released back in the exosphere with the morning illumination. Such enhancements are not detected by the other groups, which claim for ion sputtering as the dominant source mechanism in order to explain the high emission observed in the polar region (Potter & Morgan 1997).

The apparent contradictions in the results of the various groups of observers, as well as the lack of an entire explanation of the nature of the exosphere, is largely due to different observing techniques and geometries, and to the difficulty of the observations. Being so near to the Sun, Mercury is indeed very difficult to observe. It appears only for short time in the twilight with large zenith distance, i.e. with large air masses, poor seeing and strong terrestrial lines.

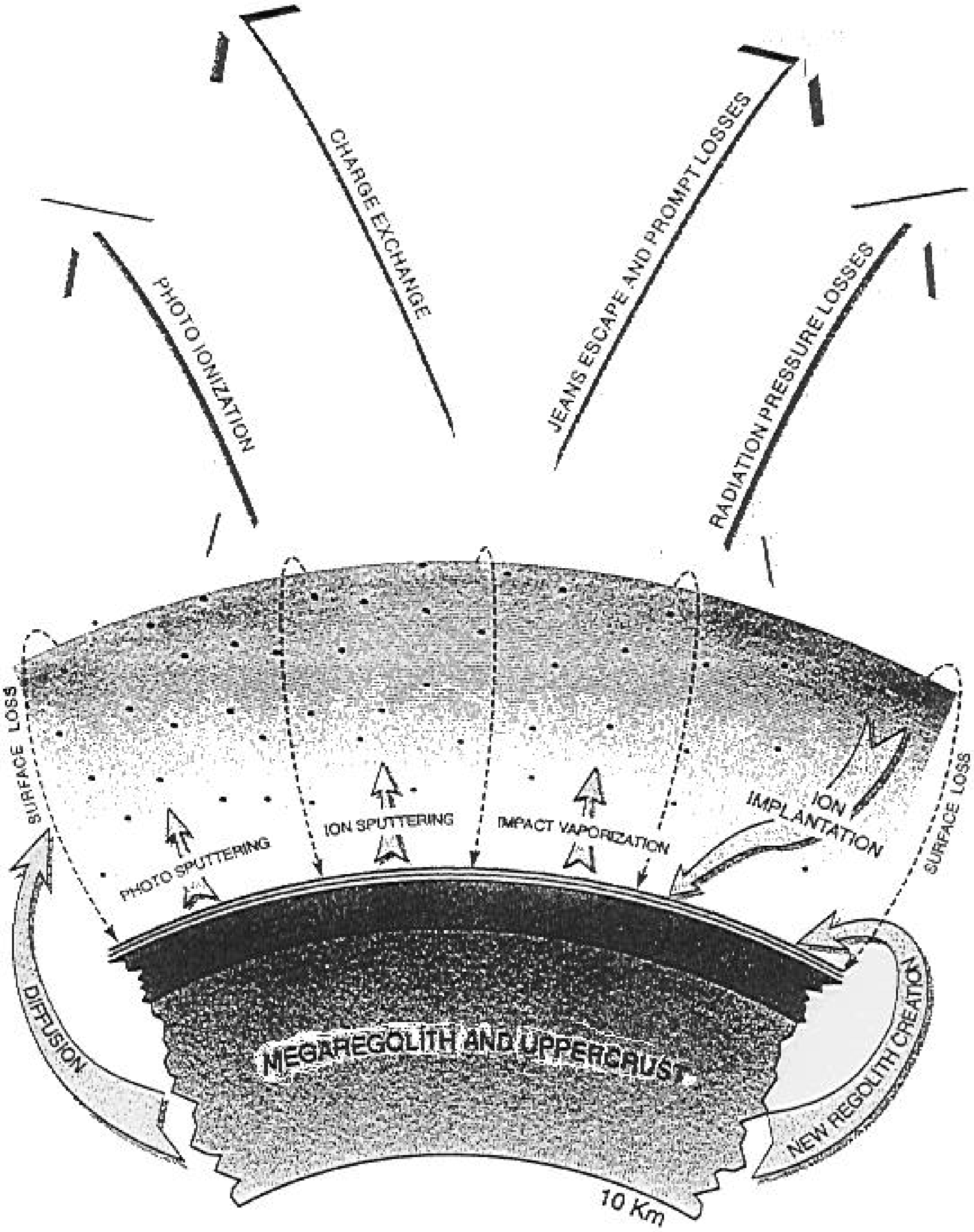


Fig. 1 – A picture of the evolution of a Na exosphere, and its interaction with the planet surface and with the interplanetary medium. Source and sink processes are shown (adapted from Killen & Morgan 1997)

Observations

We present here the first results of an observing program intended to investigate in detail if the Na atmosphere of Mercury could be studied with the SARG/TNG, and if so, to plan a future program of observations for the next several years. The advantages of using the TNG in this field of research come from the good collecting aperture, larger than most of the telescopes employed so far, from the outstanding image quality of the site and of the telescope, and from the excellent performances of the SARG in terms of efficiency and resolution. The SARG has been equipped with a Na filter specifically to this purpose of studying diffuse Na in Solar System objects, because it allows to keep a long slit (26 arcsec) on the sky. The main characteristics of the telescope and spectrograph are given in **Table 1**.

Table 1 - Instrumentation parameters

Primary mirror	3.58 m
Slit length	26 arcsec
Spectrograph resolution	115000
Pixel dimension and scale	13.5 μm, 0.16 arcsec
CCD dimension	2K x 4K pixels

Observations of Mercury's exosphere were carried out along three evenings (23, 24 and 26 Aug 2002, the 25th being lost to weather, see **Table 2**). All the measurements were made between 19:00 and 20:00 UT, namely during daytime or with the Sun just below the horizon, the minimum elevation of the TNG being 13.5 deg. Reference spectra (flat fields, bias, dark current, Th-Ar reference lamp) were taken both before and after Mercury's observations. The slit was placed at several position angles, in particular parallel to the planet's equator and perpendicular to it. The good quality of the spectra was already evident from the raw data (see **Fig. 2**).

Particular care was adopted in subtracting the sky and the Mercury continuum, in order to obtain the two emission lines from the exosphere, an example of this step in data analysis is shown in **Fig. 3**.

Table 2 - Logbooks of the spectra

Date	UT	Illuminated Fraction %	Angular Diameter (arcsec)	Slit Position Angle	Exp. Time (s)
23/08/02	19:33:55	66.3	6.34	90.00	30
23/08/02	19:40:42			90.00	30
23/08/02	19:46:06			90.00	30
23/08/02	19:48:27			180.05	60
23/08/02	19:50:43			180.05	30
24/08/02	19:46:58	65.0	6.42	152.00	30
24/08/02	19:49:17			118.92	60
26/08/02	19:19:58	62.5	6.60	28.00	60
26/08/02	19:29:18			28.00	120
26/08/02	19:37:27			28.00	180
26/08/02	19:43:18			296.00	240
26/08/02	19:46:04			296.00	60
26/08/02	19:47:49			296.00	19

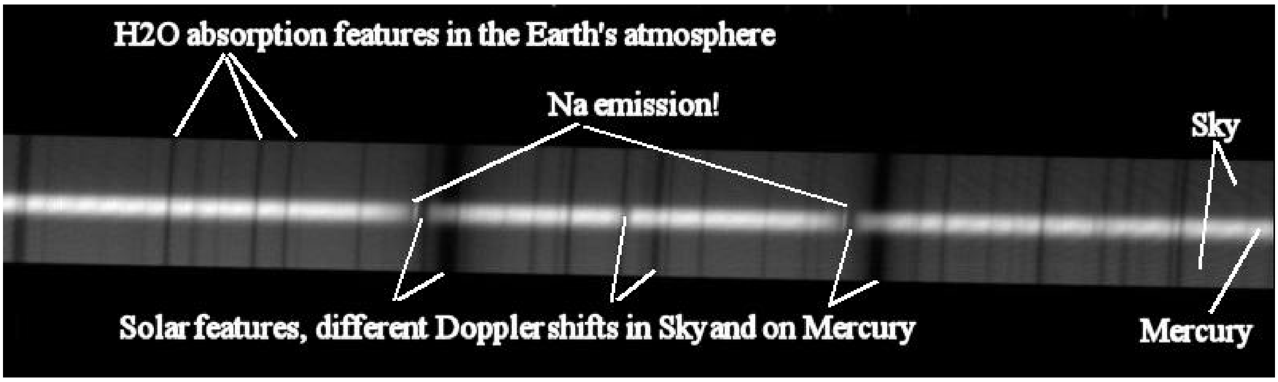


Fig. 2 – One of the raw data with identification of the main features.

Absolute calibration in flux were performed using a spectrum of a standard star (Spica), observed every night just after (or before) Mercury.

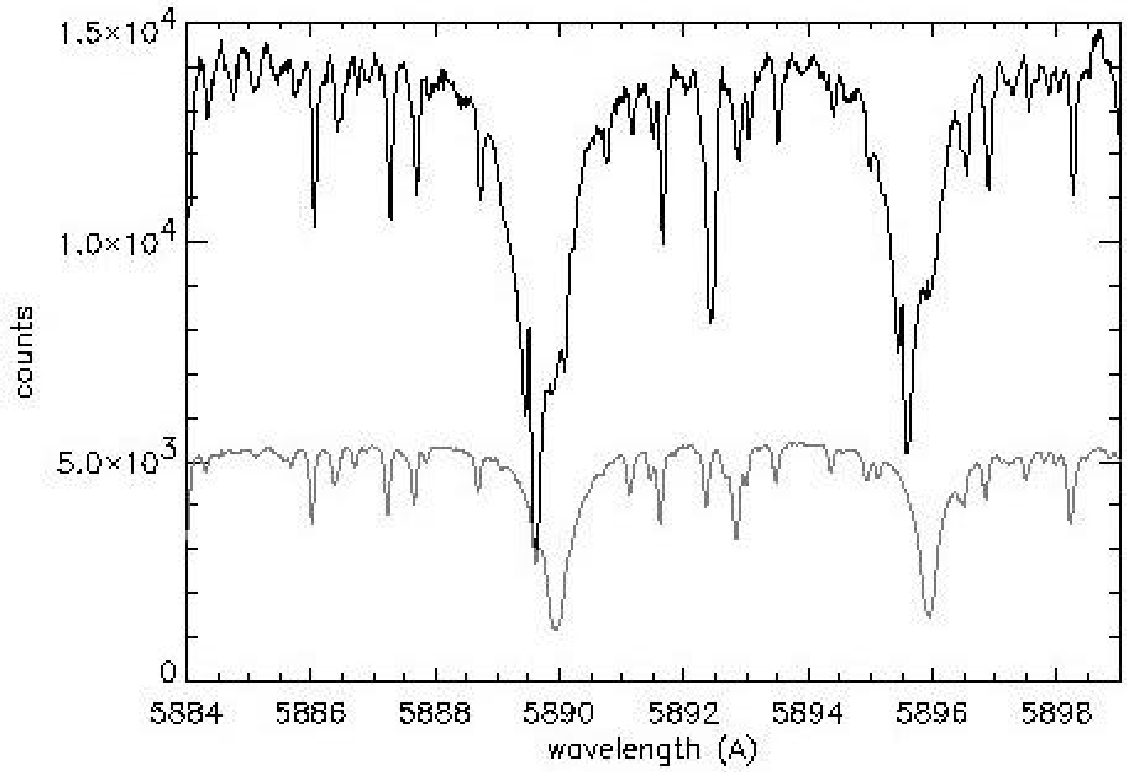
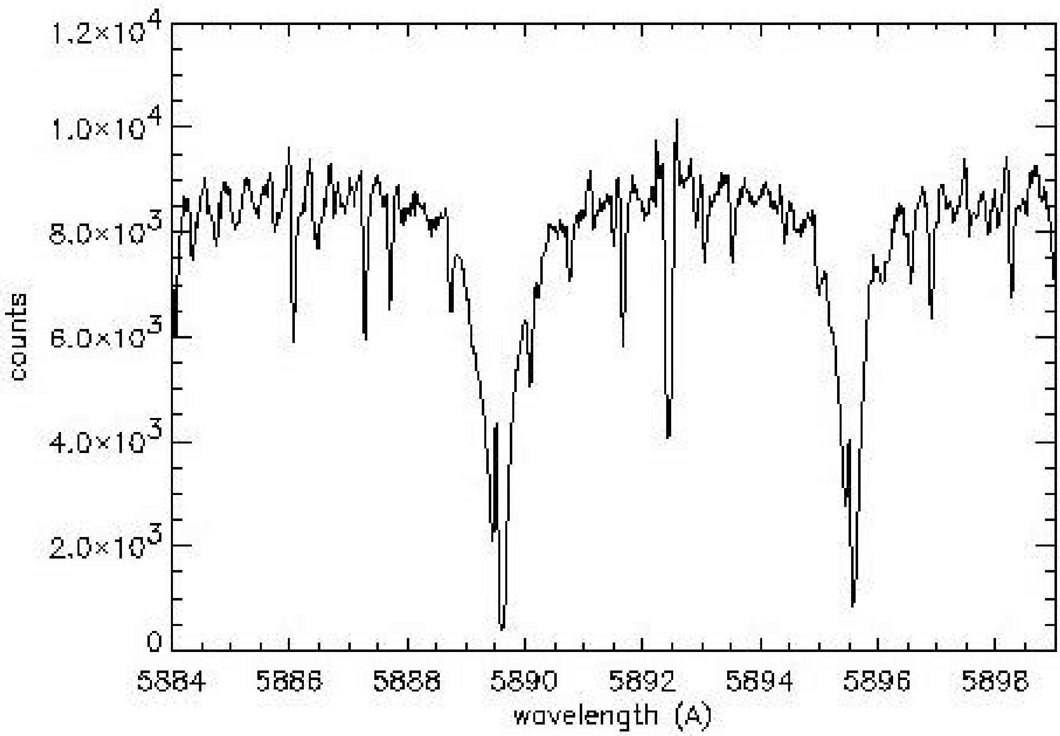
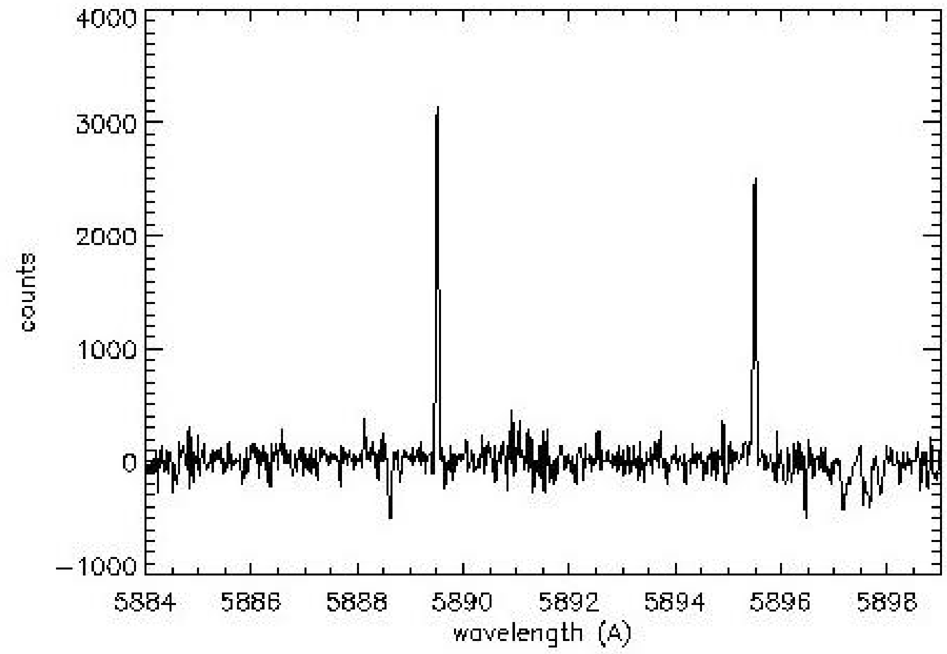


Fig. 3a) **plot of Mercury + sky spectrum (up) and of the sky only (bottom)**



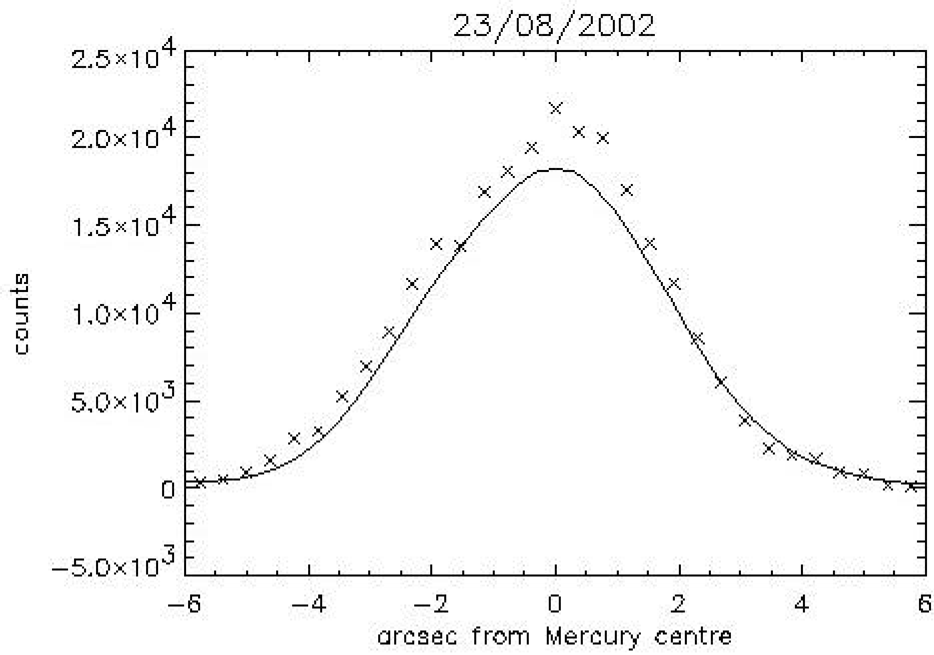
b) **After sky subtraction: solar continuum reflected by Mercury surface and the exospheric D1 and D2 emission**



c): **After solar reflected spectrum subtraction: the exospheric spectrum with the D1 and D2 Na emission lines**

Main Results

- ?? *Detection of Na emission across the planet's disk but not outside it (see Fig. 4)*
- ?? *No noticeable spots in Na emission found along the slit*



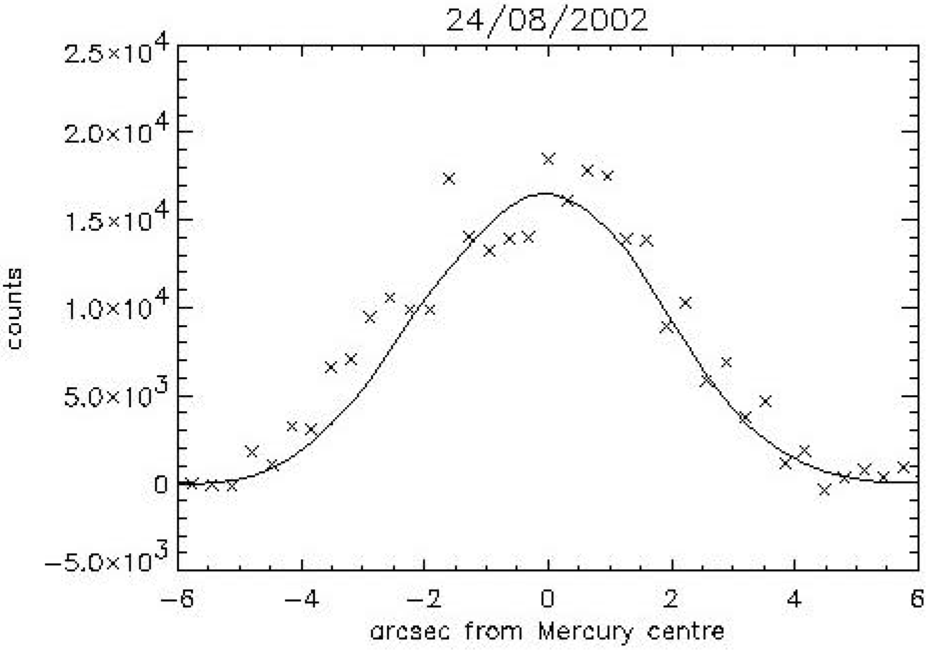


Fig. 4 – The continuum (solid lines) and the D2 emission ("x" points) for two dates. Outside the "seeing smear", no Na emission is detected.

?? *Estimate of emission (see **Table 3**) in good agreement with the values reported in literature*

Table 3 - Average column density at the center of Mercury's disk

DATE	Column density (Atoms/cm^2)
23/08/2002	(4.1?0.4)x10^{11}
24/03/2002	(4.8?0.5)x10^{11}
26/03/2002	(4.3?0.4)x10^{11}

?? *Agreement of the measured shift of the D1 and D2 observed Mercury emission lines wavelength with respect the rest wavelength and the shift calculated for these lines from the measurements of the Mercury-observer radial velocity (see **Table 4**)*

Table 4 – Radial velocities

Date	Mercury's Radial velocity (Horizon JPL)	Measured Na Radial Velocity
	(Km/s)	(Km/s)
23/08/2002	-23.2364	-22.4 (?0.6)
23/08/2002	-23.2136	-23.6 (?0.6)
24/08/2002	-23.5354	-22.7 (?0.6)
24/08/2002	-23.5121	-23.0 (?0.6)
26/08/2002	-24.1171	-23.9 (?0.6)
26/08/2002	-24.0843	-23.9 (?0.6)

Next goals

??*Development of an appropriate Hapke model for absolute flux calibration, and fuller discussion of Table 3with due account of g-factor (Sprague et al., 1996)*

??*Observations with a slit of better optical quality, in order to reduce the diffused light into the instrumentation*

??*Long term observation's campaign, in order to check the evolution of the exosphere with solar cycle and the planet's orbit*

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